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The study described in this paper was done in the context of a Petri net model (generalized stochastic Petri net or GSPN model) of a simulation network similar to SIMNET, a distributed system of training simulators connected over an Ethernet local area network. In this report, the execution time of a stochastic Petri net model of a specific distributed application using Ethernet is used to determine the largest model that can be analyzed on a Sun workstation in a reasonable time. The time for the solution of the SIMNET models was measured using two different configurations of the Sun Workstation. The data collected indicates that increasing the storage capacity of the workstation increases the size of the model that can be solved in a reasonable time. The degradation in performance with an increasing number of markings is more gradual with larger memory. A number of tables are included in the report which illustrate the outcome for each of the three models examined.

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Execution Time Requirements of Petri Net Programs in a Sun Workstation Environment

ABSTRACT

We are presenting results of our work with generalized stochastic Petri net (GSPN) models. We consider execution time requirements of Petri net programs. The interest is in finding the size of the largest model which can be analyzed using a Sun workstation. The study is done in the context of a Petri net model of a simulation network similar to SIMNET, a distributed system of training simulators connected over an Ethernet local area network.

INTRODUCTION

The size and complexity of the system whose performance can be analyzed is limited by the available computation facilities. When stochastic Petri net models are used, the major computation steps are the determination of the reachability tree of the net and the solution of the resulting continous time Markov chain. The time required for these two steps is determined by the size and complexity of the Petri net model and the computational capabilities of the computer system where the solution procedure is implemented. With a Petri net model, it may be possible to find approximate models which are simpler than a detailed model but still provide adequate precision. Thus, it is necessary to balance the size of the system being modeled andthe detail with which the system components are described in the model. The use of such simplified models is illustrated in the context of simulation networks by the various global models of the simulation network as described in a separate technical report.

The second option which can be utilized to increase the size of system which may be analyzed is the use of computational facilities with greater capabilities. This report describes experimentation with computational facilities with the aim of determining the Petri net model size which can be analyzed. The study was performed by comparing the time required to solve models of a simulation network on two different hardware configurations.

In this report, we use the execution time of a Stochastic Petri Net model of a specific distributed application using Ethernet to determine the largest model that can be analyzed on a Sun workstation in a reasonable time. The performance of the Ethernet local area communication network has been extensively analyzed with varying degrees of detail ([Go'85], [Gr'85],[MaCh'87], [ToHu'80],[TaKl'85]). The distributed application we consider is provided by a network of training

simulators which interact with each other using communication over a local area network. Although the network has been analyzed using two different models of Ethernet, only one has been used for this study. The approach used in this model is to simulate the concurrent behavior of all stations rather than modeling only one station along with the expected effects of the remaining stations on this one station, as done by Greisser [Gr'85]. In this regard, our model is similar to that of Marsan et al. [MaCh'87]. Our model, however, differs from Marsan's model in that we model the message loss which occurs when the number of allowable transmission attempts is exceeded. We are primarily interested in the loss of messages since this can have both short- and long-term effects on the appearance of the simulation to the trainees. Several models are described in this paper. The first one gives an exact representation of the collision handling process in Ethernet. The other models are based on close approximations of this process to allow solutions with a larger number of nodes. In the following section, we describe the operation of the simulation network then proceed to present the Stochastic Petri Net models of the combined training simulator/Ethernet combination.

We first describe the Petri net model used for the simulation network, SIMNET. Next, we describe the hardware and software solutions tried in our study. This is followed by the presentation of the results of the study. Finally, we present our conclusions.

SIMNET

SIMNET is an experimental project [Po '89],[FrHa '88] sponsored by DARPA and the US Army (PMTRADE) and developed by researchers at BBN to develop a distributed battlefield training simulation system by networking large numbers of interactive combat vehicle simulators and their supporting elements. A detailed description of the SIMNET system is given in [Po '89], [FrHa '88]. Since our Petri net model development is influenced by the SIMNET system, a brief description of this system and its networking scheme follows. Excerpts from [Po'89], [FrHa'88] provide this description.

The SIMNET vehicle simulators and their supporting elements communicate via local area and long haul networks. Simulators at a single site are connected via a 10 Megabit per second Ethernet (Ethernet is a registered trademark of the Xerox Corporation). Each Ethernet is connected to a single long haul network by a gateway. Since our model development at this point is for a single site, we restrict the discussion only to local area networks.

At each SIMNET site there is a set of tank and aircraft simulators. The Management, Command and Control (MCC) system at the site initializes these simulators and simulates indirect fire, close air support, and resupply and repair vehicles. Each simulator periodically broadcasts an update of its status (position, orientation, velocity, and other descriptive characteristics). These update messages are the major source of traffic on the network. A dead reckoning algorithm is used to decrease the number of these messages. In this algorithm, each simulator extrapolates the status of other simulators . Each simulator also extrapolates its own status. If this extrapolated information differs from the actual information by more than a predetermined amount, the simulator transmits a new update message so that it can be used by all simulators on the network. These update messages are transmitted according to a protocol, called the simulator protocol, which has been implemented as an application layer protocol making direct use of the network layer services with no intermediate layers. In addition there are other protocols which implement the other functions of SIMNET. However, the impact of the simulator protocol on the network traffic is the most significant one (compared to the other protocols).

THE MODELING APPROACH

It is evident that there are two distinct architectures that need to be modeled and combined together to make the system development modular. One is the architectures of the communication network and the other is the distributed SIMNET architecture which utilizes the communication protocol for information transfer. Since Ethernet is available commercially, the communication architecture at a single site has been implemented by Ethernet and all SIMNET protocols are implemented as application layer protocols on top of Ethernet. In our modeling efforts, we first develop a high level model for each of the two architectures and then gradually develop the low level details by expanding on the high level models. Even at this high level of modeling, the development of the details of the communication network architecture is necessary to determine any data loss due to communication networks. We start by developing a global model of the network architecture with a very high level description of the SIMNET architecture and details of Ethernet frame transmission attempts. We then modify this global model of the network architecture by introducing approximations that allow the execution of a larger number of nodes while maintaining a high degree of accuracy.

GSPN MODEL OF SINGLE SITE SIMULATION NETWORKS WITH ETHERNET

The transmission process of a given node consists of three parts corresponding to the three processes defined by the Ethernet protocol or the MAC sublayer of IEEE standard 802.3 [Ie '85].

These processes are the frame transmitter process, the deference process, and the bit transmitter process .

Global Model 1:

This global model incorporates strong interaction among all stations in the simulator network in order to capture the semantics of operation of the network protocol accurately. To obtain an analytically solvable model based on the underlying Markov chain, all deterministic transitions in this model have been replaced by exponential transitions with mean firing delay equal to the constant time.

The GSPN model that we developed simulates the operation of a frame transmitter process driven by SIMNET simulators. Sixteen chains are used to capture the state of transmission of sixteen attempts for each node. A packet is discarded if it is not successfully transmitted in sixteen attempts. In addition, the backoff delay after an unsuccessful transmission is drawn from different distributions for different attempts as specified by the IEEE 802.3 collision resolution protocol. In this model, we accurately represent the frame transmitter process keeping track of all sixteen attempts separately and using the correct backoff delay distribution for each attempt. The details are given in a separate report [GuBa'90].

Global Model 2:

Global model 2 has three chains compared to sixteen in global model 1. Chain 1 models the operation of nodes in their 1st transmission attempt. Chain 2 indicates operation of nodes in their 2nd through 10th retransmission attempts. Chain 3 stands for the operation of nodes in their 11th through 16th retransmission attempts. The exponential transition in the 2nd chain in global model 2 actually models the weighted average of backoff delays in chains for retransmission attempts 2 to 10 in global model 1. Also the mean delay of the exponential transition in chain 3 is the backoff delays in chains for retransmission attempts 11 to 16 in the previous model. Four random switches with appropriate probabilities are used and are divided into two groups. The two random switches in the first group perform two distinct operations. One of them keeps nodes in chain 2 while the other moves them to the starting place of chain 3. Similarly, one of the two random switches in tne 2nd group keeps nodes in chain 3 and the other one transfers them to the starting place of chain 1. With this modified model based on suitable assumption for backoff

delays and probabilities of random switches, a substantial reduction in the size of the reachability graph is obtained compared to Global model 1.

Global Model 3:

Global model 3 is a further simplification of global model 2. It has two chains compared to sixteen in global model 1 and three in global model 2. Chain 1 implies operation of stations as in chain 1 of Global model 1 and 2. But chain 2 indicates operation of stations in their second through 16-th retransmission attempts. The exponential transition at the beginning of chain 2 models the weighted average of backoff delays in chains for retransmission attempts 2 to 16 in Global model 1. Two random switches with appropriate probabilities either keep stations in chain 2 or move them to the starting place of chain 1.This model gives further reduction in the size of the reachability graph over Global model 2.

HARDWARE USED FOR THE STUDY

We compared the time for the solution of the SIMNET models on a Sun Workstation with two different configurations. The first configuration was equiped with 4MBytes of main memory while the second was equiped with 16 MBytes of main memory. The secondary storage space allocated for paging was also increased from 32 MBytes to 264 MBytes in the 16 MByte case. This increased space was provided by an additional hard disk unit. We also installed a new version of the Petri net analysis program on the upgraded workstation. This new version reduces the storage requirement for large models.

MODEL SIZE AND EXECUTION TIME COMPARISON

All three global models described above were analysed with tools under GreatSPN and SPNP packages.Table 1 gives the comparison of the reachability graph for these three models. Table 2 provides a comparison of the execution time of global model 3 with two different sizes of primary memory. The data from Table 2 is also given in Figures 1 and 2. Figure 1 shows the relation between the number of clusters and the markings and arc in the reachability tree while Figure 2 shows the dependence of execution time on the number of tangible markings.

The data shows that increasing the storage capacity of the workstation increases the size of of the model which can be solved in a reasonable time. Further, the degradation in performance with increasing number of markings is more gradual with the larger memory. With the first

configuration, the time to solve a model of a particular size gives little information on the time required for a slighly larger model. This can be easily seen in Figure 2.

It should be noted that the definition of "reasonable" has been set at a solution time of about 24 hours. Thus, although the size of the model which can be solved has been increased, the time for the largest models is such as to reduce the amount of analysis which can be performed on these.

No. of Clusters	Global Model 1	Global Model 2	Global Model 3
2	T=1192 V=1704 A=3648	T=48 V=66 A=150	T=23 V=31 A=68
3	T= 17852 V= 22576 A=62304	T=168 V=216 A=583	T=60 V=78 A=196
4	T= ?? V= ?? A=??	T=444 V=560 A=1660	T=122 V=158 A=425
5	T= ?? V= ?? A=??	T=981 V=1233 A=3903	T=214 V=278 A=779
6	T=?? V=?? A=??	T=1919 V=2417 A=7993	T=341 V=445 A=1282
7	T=?? V=?? A=??	T=3438 V=4348 A=14862	T=508 V=666 A=1958
8	T=?? V=?? A=??	T=5763 V=7323 A=25695	T=720 V=948 A=2831
9	T= ?? V= ?? A=??	T=9169 V=11707 A=41968	T=982 V=1298 A=3925
10	T= ?? V= ?? A=??	T=13986 V=17940 A=65480	T=1299 V=1723 A=5264

Table 1. Comparison of the reachability graph of the three global models
T= tangible marking, V= vanishing marking, ??= not attempted
A= Number of Arcs

No. of Clstrs	Tangible Marking	Vanish Markings	Arcs	Execution 4 MB Ram	Execution 16 MB Ram
20	3578	3601	13108	14 mins	15mins
25	6598	6626	24573	46 mins	41 mins
30	10968	11001	41313	135 mins	107 mins
35	16938	16976	64328	278 mins	253 mins
40	24758	24801	94618	2062 mins	573 mins
41	26566	26610	101637	??	723 mins
42	28460	28505	108995	??	824 mins
43	30442	30488	116700	??	958 mins
44	32514	32561	124760	??	1056 mins
45	34678	34726	133183	??	1401 mins
46	36936	36885	141977	??	1406 mins

Table 2. Reachability graph and execution time with two different size of RAMs

CONCLUSIONS

In this report, we have presented the results of a study of the effect of increasing storage on the execution time for Petri net programs. All the improvements considered to the Sun workstation worked to reduce the time to access data. The additional disk space provided additional storage for large models and access to this storage was facilitated by additional main memory to serve as a cache memory for disk data and the new analysis software reduced the amount of secondary storage required for model solution. None of the improvements increased the main processor speed, demonstrating the requirement for quick access to secondary stroage in order to realize the full processing power of the main processor. Of course, the use of newer Sun workstations with faster processors could be expected to reduce the running times from the one day now required on the largest models to several hours.

FIGURE 1

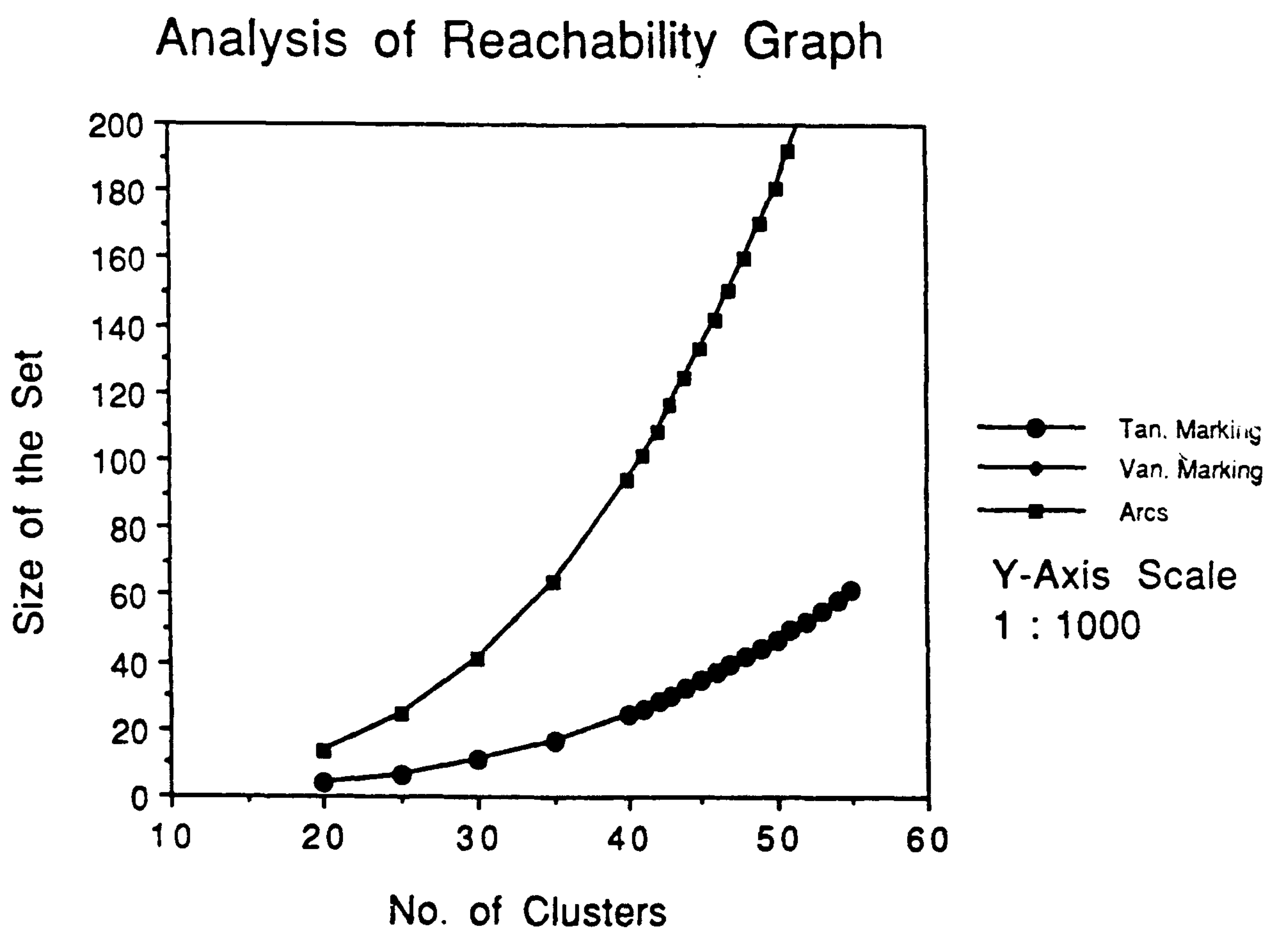
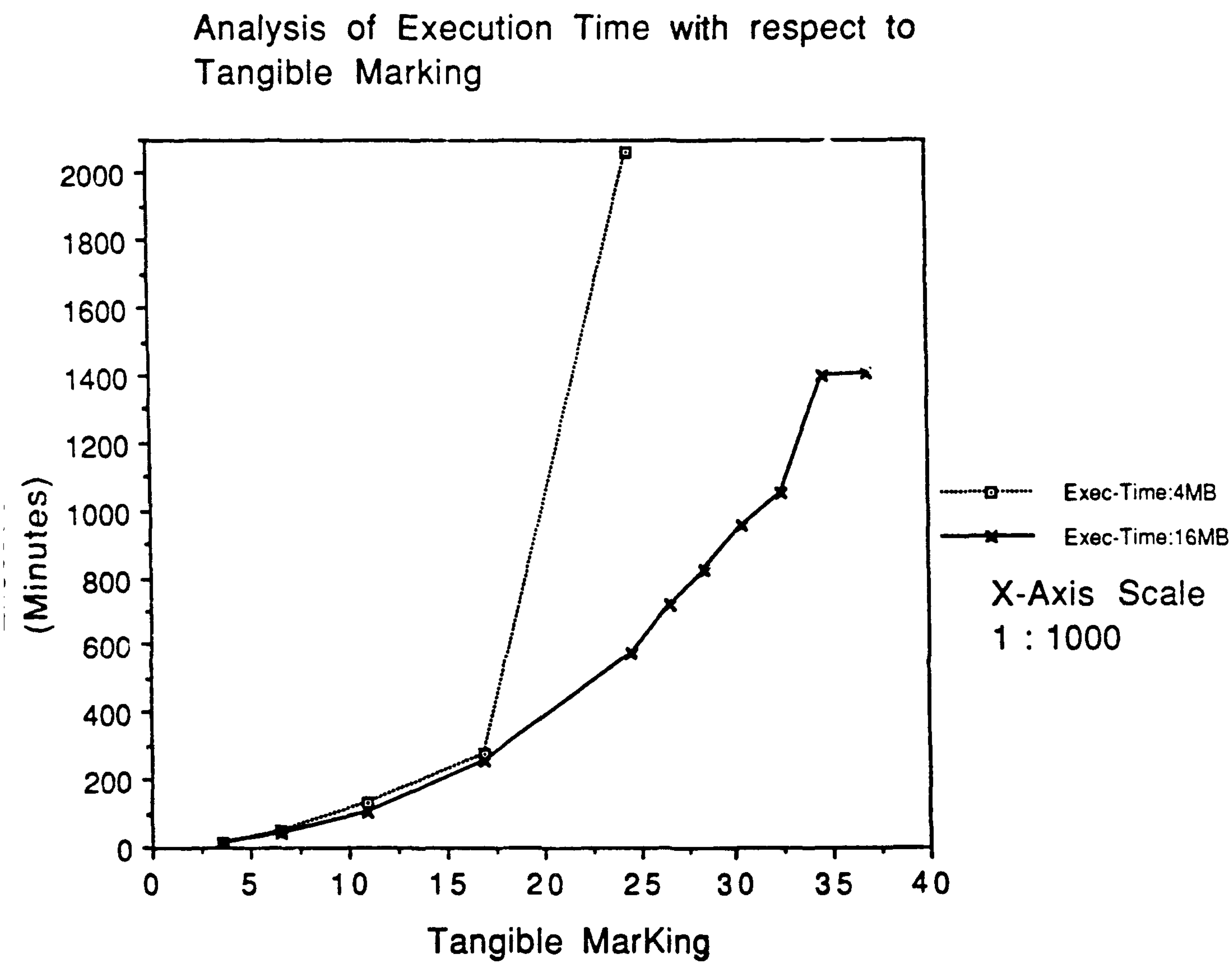

Analysis of Reachability Graph
200
180
160
140
120
100
80
60
40
20
0
Size of the Set
10
20
30
40
50
60
No. of Clusters
Tan. Marking
Van. Marking
Arcs
Y-Axis Scale
1 : 1000

FIGURE 2


Analysis of Execution Time with respect to Tangible Marking
2000
1800
1600
1400
1200
1000
800
600
400
200
0
(Minutes)
0
5
10
15
20
25
30
35
40
Tangible MarKing
Exec-Time:4MB
Exec-Time:16MB
X-Axis Scale
1 : 1000

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